UNCLASSIFIED

AD NUMBER
AD862966

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; OCT 1969. Other requests shall be referred to Army Aberdeen Research and Development Center, Aberdeen Proving Ground,. This document contains export-controlled technical data.

AUTHORITY

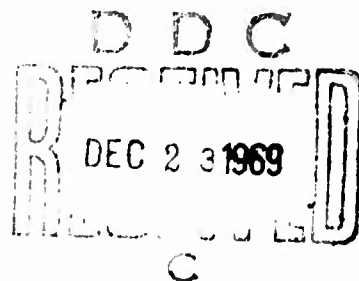BRL D/A ltr, 22 Apr 1981

THIS PAGE IS UNCLASSIFIED

BRL

MEMORANDUM REPORT NO. 2016

DEFORMATION CHARACTERISTICS OF

ONE LOT (LC SP412) OF 5.56mm M-193 AMMUNITION

by

Maynard J. Piddington

October 1969

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2016

OCTOBER 1969

DEFORMATION CHARACTERISTICS OF ONE
LOT (LC SP412) OF 5.56mm M-193 AMMUNITION

Maynard J. Piddington

Exterior Ballistics Laboratory

RDT&E Project No. 1W562604A607

ABERDEEN PROVING GROUND, MARYLAND

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2016

MJPiddington/pp
Aberdeen Proving Ground, Md.
October 1969

DEFORMATION CHARACTERISTICS OF ONE
LOT (LC SP412) OF 5.56mm M-193 AMMUNITION

ABSTRACT

The deformation characteristics of one lot of 5.56mm
M-193 ammunition are presented and discussed. Physical
measurements of the ammunition were taken before and after
launch and the results compared on an individual basis.
Rounds were launched at standard muzzle velocity, recovered
and refired at a reduced velocity and compared with other
rounds launched only at the same reduced velocity. Several
before and after launch rounds were contour measured and
comparisons were made on the shape of the projectile.

TABLE OF CONTENTS

TABLE OF SYMBOLS

C_D $\quad = \dfrac{\text{Drag Force}}{(1/2)\rho V^2 S}$

C_{D_o} $\quad =$ Zero-yaw drag coefficient

$C_{D_{\delta^2}}$ $\quad =$ Yaw drag coefficient

C_{L_α} $\quad = \dfrac{\text{Lift Force}}{(1/2)\rho V^2 S \alpha_t}$ Positive coefficient: force acts in the direction of the angle of attack α_t.

C_{N_α} $\quad = \dfrac{\text{Normal Force}}{(1/2)\rho V^2 S \alpha_t}$ Positive coefficient: force acts in the direction of the angle of attack α_t.

C_{M_α} $\quad = \dfrac{\text{Static Moment}}{(1/2)\rho V^2 S \ell \alpha_t}$ Positive coefficient: moment increases angle of attack α_t.

$C_{M_{p\alpha}}$ $\quad = \dfrac{\text{Magnus Moment}}{(1/2)\rho V^2 S \ell \frac{p\ell}{V} \alpha_t}$ Positive coefficient: moment rotates missile nose in direction of spin.

For most exterior ballistic uses, the definition of the damping moment sum is equivalent to:

$C_{M_q} + C_{M_{\dot\alpha}}$ $\quad = \dfrac{\text{Damping Moment}}{(1/2)\rho V^2 S \ell \frac{q_t \ell}{V}}$ Positive coefficient: moment increases angular velocity.

CP_N $\quad =$ Center of pressure of normal force. Positive from base to nose.

S $\quad = \dfrac{\pi d^2}{4}$

$\bar\alpha_t$ $\quad = \arcsin \sqrt{\overline{\delta^2}}$

δ $\quad = \sin \alpha_t$

$\overline{\delta^2}$ $\quad = /K_1^2 + K_2^2/_Z = Z^*$

7

TABLE OF SYMBOLS (Continued)

$$\delta_c^2 = K_1^2 + K_2^2 + \frac{\phi_1' K_1 - \phi_2' K_2}{\phi_1' - \phi_2'}$$

$$\delta_{e_i}^2 = 2(K_1^2 + K_2^2) - K_i^2$$

$$\delta_{e*}^2 = -\frac{I_y}{I_x} \frac{\phi_1' + \phi_2'}{\phi_1' - \phi_2'} (K_1^2 - K_2^2)$$

ρ air density

ν non-dimensional spin

α_t total angle of attack

$\lambda_{1,2}$ damping rates

$\phi_{1,2}'$ turning rates

a_{L2} cubic term in the equation:

$$C_L = [C_{L_{\alpha_0}} + a_{L2} \alpha_t^2] \alpha_t$$

d body diameter of projectile

cg center of gravity

$K_{1,2}$ yawing vectors

ℓ reference length (for this report $\ell = d = .223$ inches)

M Mach number

p rolling velocity

q_t angular velocity

SN serial number

s gyroscopic stability factor

I_x axial moment of inertia

8

TABLE OF SYMBOLS (Continued)

I_y	transverse moment of inertia
Rd	round number
S_L	radius of swerve
V	velocity of missile
Wt	weight
Z	downrange distance
Z*	mid-range of observations
$[\ ]_R$	range values

INTRODUCTION

In recent years, there has been a considerable amount
of aerodynamic testing done with the smaller caliber
bullets, 7.62mm and smaller. Results of some of these tests
are given in References 1 through 4. One characteristic of
all of these data which surprised the testers, whose
familiarity was with larger projectiles, was the large
amount of scatter in the individual results. It was not
uncommon to find at least ten percent scatter among the
results for a given aerodynamic property whereas the
statistical error of an individual C_D determination is less
than one percent. There were also two other disturbing
features about the data for the 5.56mm M193 bullet. The
data trends as a function of Mach number seemed to be
different **from those** predicted based on bullet drawings.
Detectable discrepancies appeared between predictions based
on the aerodynamic data taken at low supersonic speeds
using reduced velocity firings and the actual behavior of
the round fired at normal velocity and reaching the same
Mach number at longer range. This appeared through the
development of a limit cycle yaw whose amplitude was not
correctly predicted by the data from the simulated test.

Several plausible reasons were advanced for one or
more of these problems. The first of these was the
deformation during the launch cycle; the bullet is swaged
into the tube rifling as a normal part of the launching and
at the least this will produce local deformation on the
bullet surfaces in contact with the bore. In the case of
the M193 bullet, in-flight shadowgraphs also indicated
ogival and boattail section changes. Thus, it was argued
that computations based on the prefired shape of the
projectile could have systematic differences because of the
different in-flight shape and that testing at lower launch

11

velocities could also yield different results because the lower load launch condition would yield less deformation and hence a different shape. Further, it was argued that the variability in this process could result in round-to-round variability in the data. Certainly these conditions occur to some degree but the question is whether the end result produces significant differences in the stability behavior. This hypothesis led to the present program. A second reason, spin mismatch, was also proposed to explain the observed behavior and is the subject of a separate study.

The primary objective of the present program was to determine the differences between the aerodynamic and stability properties of bullets launched under normal service load conditions and those of bullets with minimal deformation. The principle interest was in the net differences in average behavior since only these could explain the apparently systematic discrepancies. It was, of course, essentially impossible to ignore the effect on individual differences; **this bears on the round-to-round problem.** In addition, the process of testing more projectiles sheds further light on the lot-to-lot variations and also firms the knowledge on the average properties of the M193 bullet. These items, not necessarily related to the main purpose of the test, are also reported.

In conducting the tests, care was taken to avoid conditions that have proven to be causes of variability, or those that could be if deformation proved to be a serious problem. These have confused some past comparisons and are:

1. Variability between lots of a given manufacturer.

2. Variability between the lots of various manufacturers.

3. Variability between bullet-weapons interactions in **different weapons.**

12

The bullet selected for this study was the 5.56mm M193. This was done for two reasons; first, considerable data has been obtained with this projectile which can be used for various comparisons, and second, the program serves to expand the understanding of the M16 rifle system -- a current task under the Army Small Arms Research Program.

TEST PROCEDURE

One lot of ammunition, LC SP412, and one rifle, SN 023199, were used exclusively; other data involving the same combinations can be found in Reference 1 and in part of Reference 2. Both of the free flight range facilities of the BRL were used; the Transonic Range[5]* for the preliminary firing and the smaller Aerodynamics Range[6] for the aerodynamic data testing.

In the study of the effects of deformation, it is necessary to compare the data from normally deformed bullets (NDB) with data obtained from relatively undeformed bullets that have also been fired through the same barrel. For the purpose of this report, these latter bullets will be termed low deformation bullets (LDB) since the engraving process necessary to impart spin will produce some deformation and their form will be different from unfired bullets (UFB). Obviously, both NDB and LDB can not be readily produced by launching unfired bullets at standard muzzle velocity since all rounds under these conditions would fit into the NDB category. Firing the bullet at reduced velocities, and hence reduced pressures, should produce bullets of lower deformation. In order to provide NDB for the same conditions as for LDB, rounds were first fired at standard conditions, recovered in a soft medium,

---

*Superscripts denote references, found on Page 21.

13

and then separately reloaded into the barrel for the reduced velocity firings in the aerodynamic testing. The data obtained from these rounds were compared with those from LDB fired only at the reduced velocity.

The method used to recover the bullets is described in detail in Reference 4. Briefly, it consisted of placing a six foot thick stack of foam rubber saturated with water at about 600 meters from the weapon and firing into it. The rifle was mounted in a Frankford rest to provide for accurate adjustment of the trajectory. The projectiles impacted at about 365 mps and previous tests have shown that under these conditions no visible deformation of the M193 bullet is incurred in the recovery medium.

Measurements of the physical properties[7] (Table 1) were made on fourteen unfired rounds. Ten of these projectiles were recased and along with twelve additional rounds were fired, recovered and measured. The results are compared on an individual basis in Table 1. In order to define the shape of the bullet better before and after launch, contour measurements were made on ten unfired rounds (four of these are listed in Group 1, Table 1) and nine NDB (Group 2, Table 1) by measuring the diameter of the projectiles at 2.54mm intervals using a Mann optical comparitor.

The major portion of the aerodynamic testing of the LDB and NDB was conducted at Mach 1.25 and 1.60. Some additional rounds with UFB were fired at higher Mach numbers to provide connection with the previous data in Reference 1. As the test speed was increased toward normal muzzle velocity these projectiles sustained higher pressures and would, presumably, undergo a transition from what is termed LDB to NDB.

14

RESULTS

Range Data

At the outset of the program only the peak pressure at standard muzzle velocity, about 50,000 psi, was known. It was apparent that reduced muzzle velocity would yield lower values, but it seemed relevant to determine the value of the peak pressure at these reduced velocities more exactly. Inquiry revealed that very little data was available on peak chamber pressure at subnormal muzzle velocity for the M16 rifle. Appreciation is extended to Mr. R. Geene, of the Interior Ballistics Laboratory, for conducting a limited test to produce the curves shown in Figure 1. The data are not based on the ammunition or the rifle used in the exterior ballistics tests. This side investigation yields some general enlightenment, but Mr. Geene cautions that the limited amount of testing utilized means that these curves should be considered only as approximations and should not be considered as a reliable indication of the typical performance of the M16 rifle system. They are certainly adequate to show that at the lower velocities used, the peak pressures are considerably lower than normal and are about 15,000 psi. This substantiates the visual evidence that projectiles launched at these reduced velocities have less deformation.

The aerodynamic coefficients were reduced from the range data in the manner described in Reference 8. A summary of the aerodynamic data is given in Table 2. Drag force and moment coefficients have statistical errors less than 1/2%; errors in damping moment and lift force coefficients are on the order of 10% and 4%, respectively. The Magnus moment coefficient was computed with an actual error of about .02.

15

The moment and force coefficients are plotted in Figures 2 through 11 as functions of Mach number and yaw. Only the Mach 1.25 data are shown as a function of yaw since only at this point are there sufficient data to give a clear trend of the yaw behavior. The data at the two highest Mach numbers were obtained during previous tests and are used here to show the trends over the full Mach number range.

Two types of data appear on each of the plots -- data for ND bullets and data for LD bullets. All rounds which were launched at standard muzzle velocity either for recovery or for aerodynamic tests are considered to yield NDB data while those rounds which were launched only at the reduced velocities are all considered to yield LDB data.

The nutational and precessional damping rates, λ_1 and λ_2, are given in Figures 12 through 15 as a function of yaw and Mach number. The λ's are a function of spin and as determined from the range test reflect essentially muzzle spin conditions. These values were used together with trajectory computations to compute linearized inflight damping rates corresponding to actual trajectory conditions at a Mach number of 1.25 and these are given in Figure 16.

The gyroscopic stability factor, s, is plotted in Figure 17 as a function of launch velocity. Range determined values of s are shown for ease of comparison between the NDB and the LDB. Real range values of stability factor are normally larger than those obtained by tests at standard muzzle velocity and values of $s \cong 4$ can be expected at a range of about 500 meters.

Examination of the data curves leads to the following conclusions with regard to the aerodynamic properties:

1. Most importantly, the effect of deformation on the average aerodynamic characteristics in the case of the

16

M193 bullet is small. **The noticeable differences are:**

      (a) The overturning moment coefficient, C_{M_α}, of the NDB is about 4 percent higher than that of the LDB and this is reflected by a corresponding decrease in the gyroscopic stability factor.

      (b) There is a slight indication that there are small differences between the NDB and LDB data for $C_{M_{p\alpha}}$ and at yaw levels of less than three degrees. These data show a great deal of scatter and are not as well determined as the remaining data. Much of this data is given only in **Tables 2A and 2B.**

It is also clear that the small differences due to the deformation do not explain either the observed variability in results or the amplitude of the long range limit cycle behavior. The NDB and the LDB data show essentially the same scatter for all cases. The nonlinearities of the small yaw damping data (Fig. 14) suggest a small limit cycle but one that would differ little between the NDB and the LDB, and in neither case would approach the three to four degree levels that have been observed. The computed damping rates for real range conditions, Figure 16, further show this. They are based on the range data for yaw levels down to nearly two degrees and they indicate damping under all real range conditions. These conclusions, of course, can only strictly be applied to the 5.56mm M193 bullet.

Physical Properties

In addition to producing shape changes that influence the aerodynamic properties directly, any deformation can change the distribution of material within the bullet and, hence, the inertial factors in the stability properties. The most appropriate physical properties for each state of the bullet were used in processing the data and in computing

17

the damping and stability properties and, hence, their
effect is already included. When range round numbers are
given in Table 1, it indicates the measurements can be
associated individually with the aerodynamic data rounds.
The other aerodynamic data rounds were processed using the
average values of the most pertinent group.

The major differences in the physical properties occur
between the physicals taken before and after launch. The
small differences which appear to be consistent are:

      1. Loss in weight - about 1/2 percent.

      2. Decrease in diameter - about 1/2 percent.

      3. Decrease in axial moment of inertia - about
1 per cent.

      4. Decrease in transverse moment of inertia -
about 3/4 percent.

It should be noted that although the individual changes
are small they combine in a manner to decrease the gyroscopic
stability factor. These changes, coupled with the previous
change in aerodynamic moment, result in a net loss of 5
percent in s compared with what might be expected using,
say, design drawing information. This would hardly be
serious for bullets designed with a large safety factor but
can be relevant for those with small stability margins.

Contour Measurements

Ten UFB and nine NDB were contour measured using the
Mann optical comparitor. Diametric measurements were made
at 2.54mm intervals starting at the base of the projectile.
Averages at each interval were computed for each group to
represent the average "shape" of the two bullets and are
plotted on the same graph in Figure 18. The scale has been
expanded for ease of comparison.

18

Examination of the two shapes reveals few significant differences. About the only observable difference is shown in the boattail section where the diameter of NDB has been slightly increased and at the same time slightly rounded.

Another means of examining these data is by differencing the diameter of the average UF bullet with the diameter of the individual NB bullets. This method shows individual differences when compared to the average unfired bullet. Two examples of this determination are shown in Figure 19 and encompass the extremes of the data measurements. The horizontal scale was expanded by a factor of five to magnify these differences.

The one consistent trend is the increased diameter of the boattail section of ND bullets; there is also a slight rounding in this area. An area near the nose of the ND bullets shows a less consistent deformation, a slight decrease in diameter. There are other areas which reveal differences but they lack consistency and hence contribute primarily to round to round scatter in the data.

The result of this analysis indicates that the aerodynamic characteristic most apt to be affected by these rather small changes in shape is C_{M_α} . Free flight determination has shown this to be about a 4% increase.

CONCLUSIONS

1. The effect of deformation on the aerodynamic characteristics of the M193 bullet is a 4% increase in C_{M_α} . This change appeared to be associated with a repeatable deformation of the boattail section of the bullet during launch.

2. Small changes in physical properties of the bullet caused by deformation were observed. Combining these changes

19

with the change in C_{M_α} adversely affects the gyroscopic stability by 5%.

3. None of the above mentioned effects caused by deformation are sufficient to account for the discrepancies between the computed and the observed limit cycle yaw values.

REFERENCES

1. Maynard J. Piddington, "Comparison of the Exterior Ballistics of the M193 Projectile When Launched from 1:12 in. and 1:14 in. Twist Rifles", Ballistic Research Laboratories Memorandum Report No. 1943, 1968. AD 844934

2. Maynard J. Piddington, "Launch Characteristics of the M-193 (Ball) and M-196 (Tracer) Projectiles from the XM177E2 Submachine Gun", Ballistic Research Laboratories Memorandum Report No. 1938, 1968. AD 842938

3. Maynard J. Piddington, "Aerodynamic Characteristics of the 7.62mm NATO Ammunition M-59, M-80, M-62", Ballistic Research Laboratories Memorandum Report No. 1833, 1967. AD 815788

4. Maynard J. Piddington, "The Aerodynamic Properties of A Caliber .223 Remington Bullet used in M16 (AR-15) Rifle", Ballistic Research Laboratories Memorandum Report No. 1758, 1966. AD 489960

5. Walter K. Rogers, Jr., "The Transonic Free Flight Range", Ballistic Research Laboratories Report No. 1044, 1958. AD 200177

6. Walter F. Braun, "The Free Flight Aerodynamics Range", Ballistic Research Laboratories Report No. 1048, 1958. AD 202249

7. Elizabeth R. Dickinson, "Physical Measurements of Projectiles", Ballistic Research Laboratories Memorandum Report No. 874, 1954. AD 803103

8. Charles H. Murphy, "Free Flight Motion of Symmetric Missiles", Ballistic Research Laboratories Report No. 1216, 1963. AD 442757

No.	Rd. No.	Wt. (gm.)	L (in.)	d (in.)	cg (in. from base)	I_x (gm.-in.^{2})	I_y (gm.-in.^{2})
				UFB (Group 1)			
1*		3.549	.745	.224	.303	.0184	.1145
2*		3.529	.742	"	.300	.0182	.1140
3		3.540	.746	"	.303	.0182	.1148
4*		3.538	.748	"	.301	.0181	.1154
5*		3.547	.735	"	.299	.0182	.1147
6*		3.564	.727	"	.296	.0185	.1151
7*		3.532	.740	"	.300	.0183	.1139
8*		3.559	.746	"	.304	.0185	.1159
9*		3.564	.749	"	.303	.0185	.1152
10*		3.528	.741	"	.302	.0181	.1145
11**	9188	3.543	.749	"	.307	.0185	.1154
12**	9195	3.570	.742	"	.307	.0186	.1173
13**	9196	3.547	.737	"	.303	.0186	.1131
14**	9201	3.545	.750	"	.308	.0184	.1183
14 rd. ave.		3.547	.743	.224	.303	.0184	.1152
Ave.*		3.546	.741	.224	.301	.0183	.1148

**Used for contour measurements

Table 1.   Physical Properties
(Continued)

No.	Rd. No.	Wt. (gm.)	L (in.)	d (in.)	cg (in. from base)	I_x (gm.-in.^{2})	I_y (gm.-in.^{2})
			NDB (Group 2)				
1*		3.532	.745	.223	.303	.0182	.1141
2*	9079	3.514	.742	"	.301	.0182	.1130
3*			not recovered				
4*	9080	3.522	.749	"	.302	.0180	.1152
5*	9081	3.530	.735	"	.300	.0181	.1144
6*	9082	3.531	.727	"	.297	.0181	.1140
7*	9080	3.517	.740	"	.303	.0181	.1133
8*	9087	3.544	.747	"	.305	.0181	.1160
9*	9090	3.546	.750	"	.303	.0182	.1152
10*	9088	3.512	.741	"	.303	.0179	.1139
11		3.534	.750	"	.306	.0182	.1161
12		3.531	.743	"	.302	.0183	.1174
13	9199	3.520	.735	"	.300	.0182	.1128
14	9197	3.545	.751	"	.306	.0180	.1182
15	9198	3.534	.734	"	.299	.0182	.1145
16	9193	3.521	.741	"	.303	.0182	.1139
17	9194	3.561	.743	"	.298	.0184	.1162
18	9191	3.567	.764	"	.309	.0183	.1186
19	9192	3.520	.741	"	.304	.0182	.1132
20	9189	3.524	.732	"	.303	.0183	.1133
21	9200	3.556	.747	"	.305	.0182	.1190
22	9190	3.538	.743	"	.299	.0182	.1155
Ave.*		3.528	.742	.223	.302	.0181	.1143
Ave.**		3.534	.743	.223	.303	.0182	.1152

*Correspond to first ten rounds in Group 1. These were
  also contour measured.

**22 round average in Group 2

23

Table 2A

Summary of Aerodynamic Characteristics*

Rd.	Type	M	$\bar{\alpha}_t$ (deg)	C_D	C_{M_α}	$C_{M_q} + C_{M_{\dot\alpha}}$	$C_{M_{p\alpha}}$	C_{N_α}	CP_N (cal. from base)	s
9195	LDB	1.125	25.3	1.323	1.765	-2.25	-.20	4.89	1.79.	1.84
9196	"	1.230	5.2	.537	1.901	-2.30	-.09	2.75	2.04	1.31
9201	"	1.233	10.7	.635	1.934	-3.19	-.06	2.95	2.06	1.26
9084	"	1.251	9.4	.615	1.871	-3.27	-.10	2.93	2.01	1.30
9085	"	1.254	3.6	.487	1.902	- .04	-.27	2.70	2.06	1.21
9083	"	1.276	5.0	.515	1.880	-1.98	-.13	2.74	2.04	1.22
9086	"	1.297	3.8	.498	1.888	- .52	-.24	2.59	2.09	1.28
9091	"	1.601	5.6	.480	1.860	-2.23	-.08	3.02	1.97	1.27
9092	"	1.610	2.5	.450	1.960	- .75	-.30	2.98	2.02	1.40
9188	"	1.627	5.4	.479	1.821	-2.42	-.06	2.80	2.03	1.34
9184	"	1.759	2.6	.412	1.811	-2.93	-.17	2.68	2.02	1.31
9185	"	1.767	3.6	.422	1.805	-2.20	-.09	2.75	2.01	1.26
9187	"	1.959	1.9	.401	1.770			2.54	2.05	1.44
9186	"	1.964	4.8	.423	1.760	-2.46	-.02	2.88	1.96	1.36
9193	NDB	1.178	6.0	.576	1.955	-2.70	-.22	2.67	2.07	1.30
9198	"	1.192	17.5	.877	1.832	-2.45	-.10	3.87	1.85	1.58
9192	"	1.225	4.2	.520	1.982	-3.15	-.06	2.91	2.04	1.29
9082	"	1.249	11.0	.670	1.998	-3.15	-.08	3.13	2.02	1.34
9200	"	1.257	11.4	.668	2.000	-2.83	-.07	3.04	2.05	1.31
9191	"	1.263	6.8	.564	1.975	-3.33	-.06	2.72	2.11	1.28
9081	"	1.267	8.0	.586	1.970	-2.57	-.06	2.80	2.07	1.23
9189	"	1.271	4.0	.519	1.956	-1.94	-.18	2.83	2.05	1.31
9199	"	1.291	9.7	.631	1.917	-3.03	-.10	3.00	2.00	1.35
9190	"	1.294	5.3	.531	1.963	-2.49	-.11	2.77	2.05	1.30
9080	"	1.307	7.0	.561	1.928	-2.96	-.08	2.96	2.02	1.26
9197	"	1.320	6.3	.538	2.008	-3.30	-.06	2.81	2.09	1.22
9194	"	1.357	5.8	.547	1.946	-3.12	-.08	2.66	2.07	1.32
9090	"	1.548	2.4	.449	2.014	-3.37	-.15	2.92	2.05	1.36
9087	"	1.550	3.6	.455	1.927	-1.93	-.11	2.71	2.07	1.29
9088	"	1.564	5.3	.492	1.950	-2.42	-.06	2.78	2.06	1.35
9089	"	1.573	5.9	.525	1.878	-2.47	-.05	2.91	2.00	1.35

* If nonlinearities are present, the tabulated coefficients are presumed to be range determined values.

24

Rd.	$\lambda_1 \times 10^3$ (1/ft)	$\lambda_2 \times 10^3$ (1/ft)	K_1	K_2	δ^2_e	$\delta^2_{e_1}$	$\delta^2_{e_2}$	δ^2_{e*}
9195	8.65	1.44	.221	.365	.2107	.3156	.2310	.7898
9196	8.37	.65	.044	.079	.0078	.0144	.0101	.0544
9201	10.59	.80	.083	.167	.0294	.0630	.0419	.2969
9084	11.62	- .38	.069	.148	.0224	.0488	.0316	.2266
9085	6.92	-1.97	.023	.058	.0025	.0072	.0044	.0427
9083	9.08	- .25	.036	.080	.0056	.0140	.0089	.0755
9086	6.95	-1.69	.030	.060	.0038	.0081	.0054	.0370
9091	7.74	1.42	.054	.080	.0104	.0159	.0124	.0470
9092	7.94	-2.34	.021	.038	.0018	.0032	.0023	.0116
9188	7.42	1.38	.052	.079	.0099	.0152	.0117	.0437
9184	11.72	-2.10	.015	.043	.0015	.0040	.0023	.0211
9185	8.01	.55	.032	.054	.0038	.0068	.0049	.0256
9187		-3.98	.007	.033	.0008	.0022	.0012	.0117
9186	6.32	2.51	.051	.067	.0088	.0117	.0097	.0240
9193	13.28	-3.44	.028	.101	.0066	.0210	.0117	.1218
9198	7.97	2.08	.169	.247	.1080	.1505	.1184	.3332
9192	10.31	.61	.032	.065	.0045	.0096	.0063	.0427
9082	10.13	1.06	.096	.166	.0372	.0646	.0462	.2316
9200	9.38	1.14	.098	.174	.0386	.0700	.0496	.2762
9191	10.69	.21	.050	.107	.0115	.0255	.0166	.1238
9081	9.44	.96	.067	.122	.0170	.0342	.0238	.1519
9189	9.34	-1.04	.028	.064	.0039	.0089	.0057	.0416
9199	10.82	.06	.085	.146	.0292	.0503	.0361	.1730
9190	9.42	- .13	.041	.084	.0074	.0157	.0103	.0710
9080	10.32	.60	.055	.109	.0127	.0267	.0179	.1229
9197	11.26	.24	.042	.102	.0082	.0227	.0140	.1332
9194	10.50	- .19	.043	.092	.0088	.0181	.0121	.0838
9090	12.32	-1.53	.016	.038	.0014	.0032	.0020	.0151
9087	7.68	.26	.034	.052	.0042	.0067	.0051	.0217
9088	7.71	1.25	.051	.077	.0094	.0144	.0110	.0416
9089	7.45	1.87	.059	.085	.0123	.0178	.0141	.0458

Table 2B — Summary of Aerodynamic Characteristics*
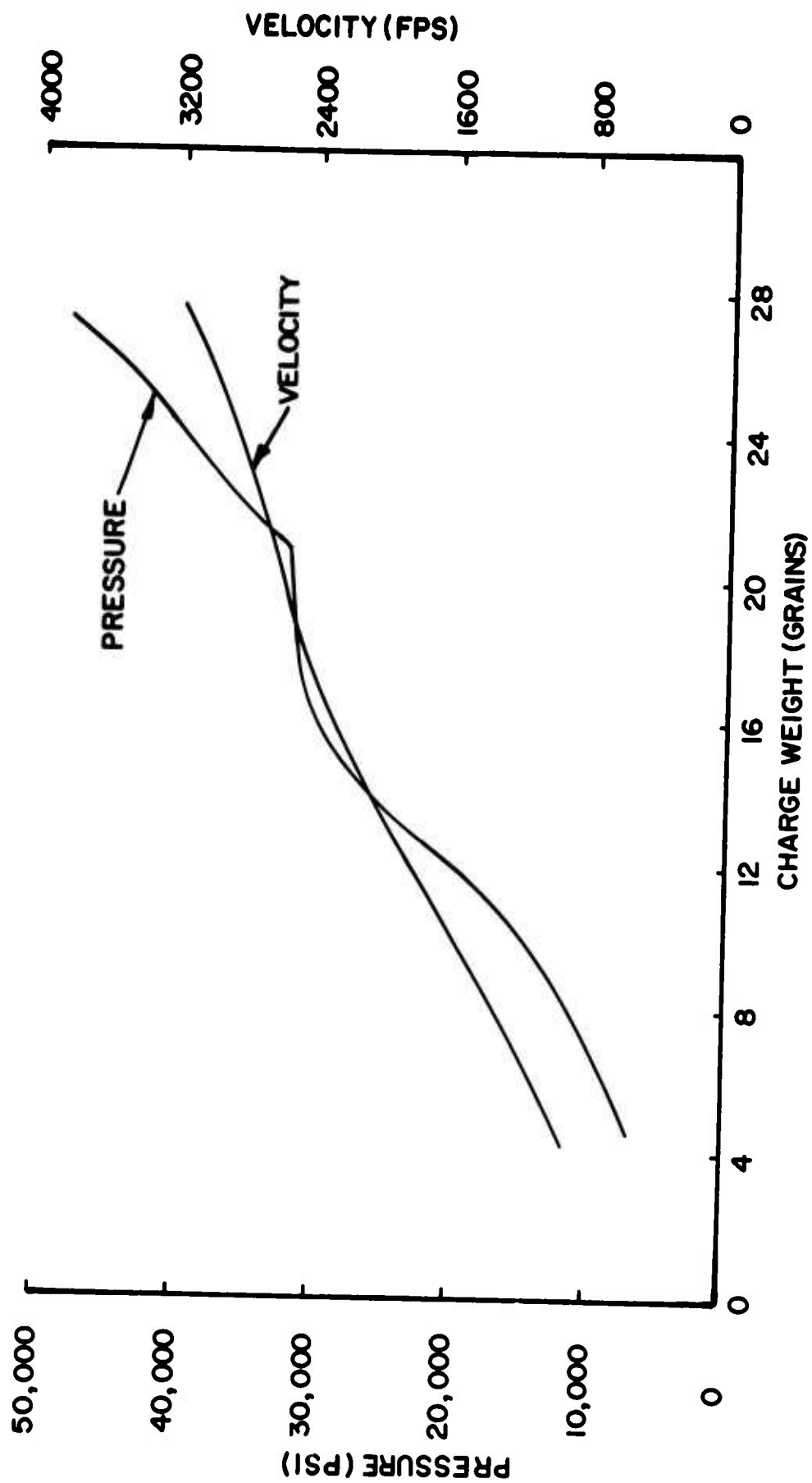
* Positive $\lambda_{1,2}$ indicates yaw damping.

25

Figure 1. Approximate Muzzle Velocity and Pressure Versus Charge Weight

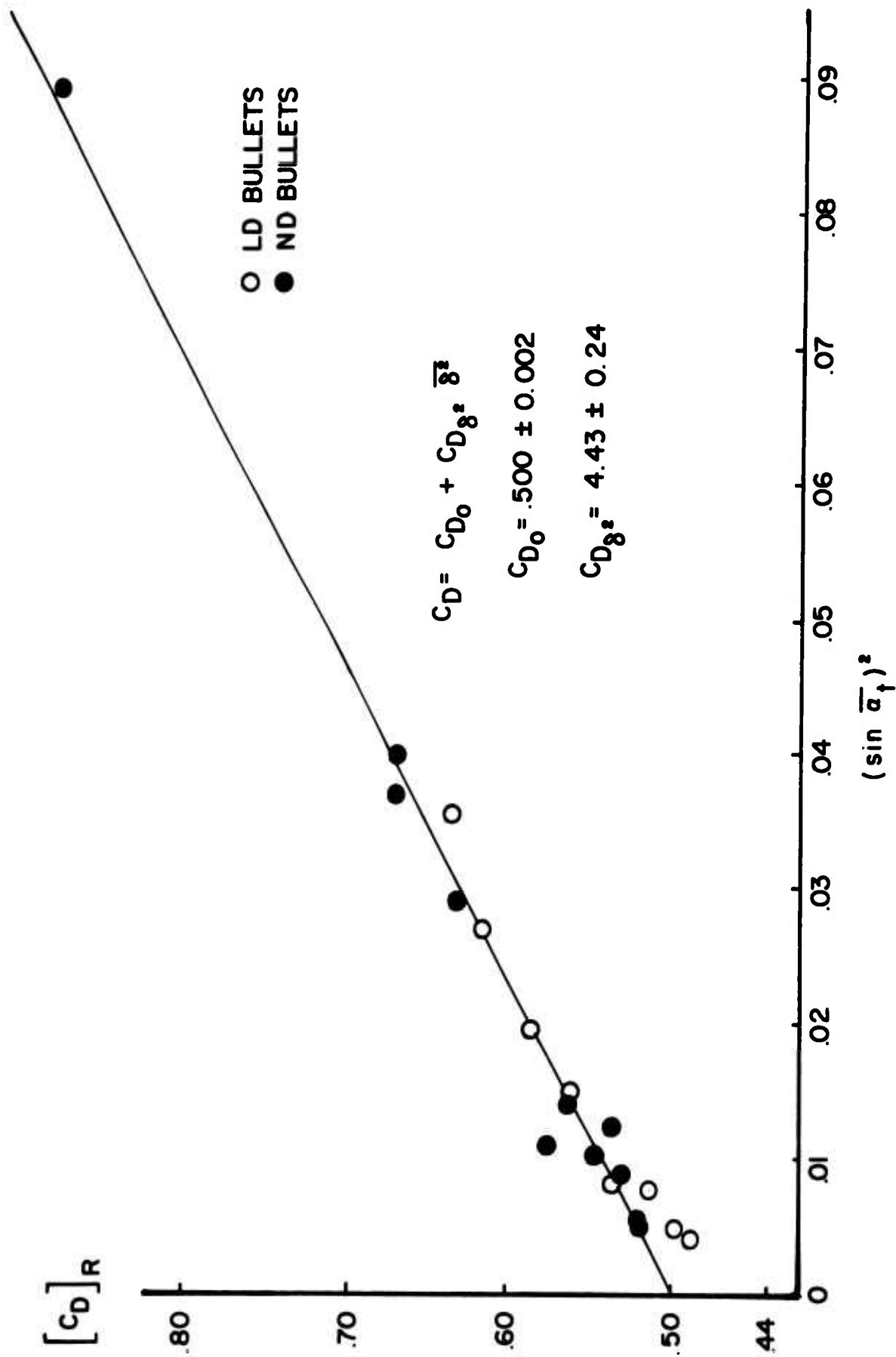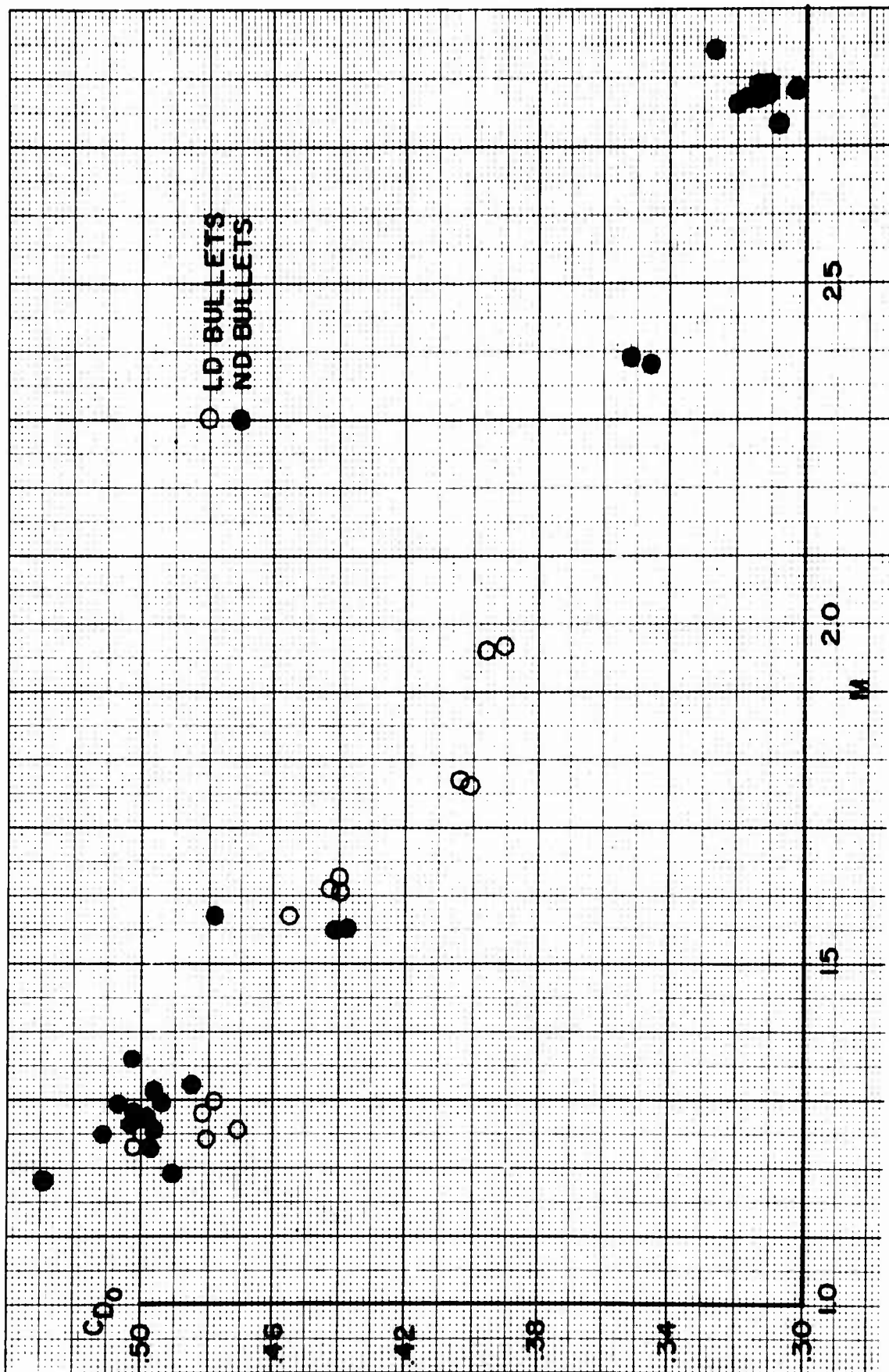Figure 2. Drag Force Coefficient Versus Mean Squared Yaw ($M \cong 1.25$)

The figure shows a plot of $[C_D]_R$ versus $(\sin \overline{a}_t)^2$ with the following data and annotations:

○ LD BULLETS
● ND BULLETS

$$C_D = C_{D_0} + C_{D_{\delta^2}} \, \overline{\delta}^2$$

$$C_{D_0} = .500 \pm 0.002$$

$$C_{D_{\delta^2}} = 4.43 \pm 0.24$$

Figure 5. Zero Yaw Drag Coefficient Versus Mach Number

28
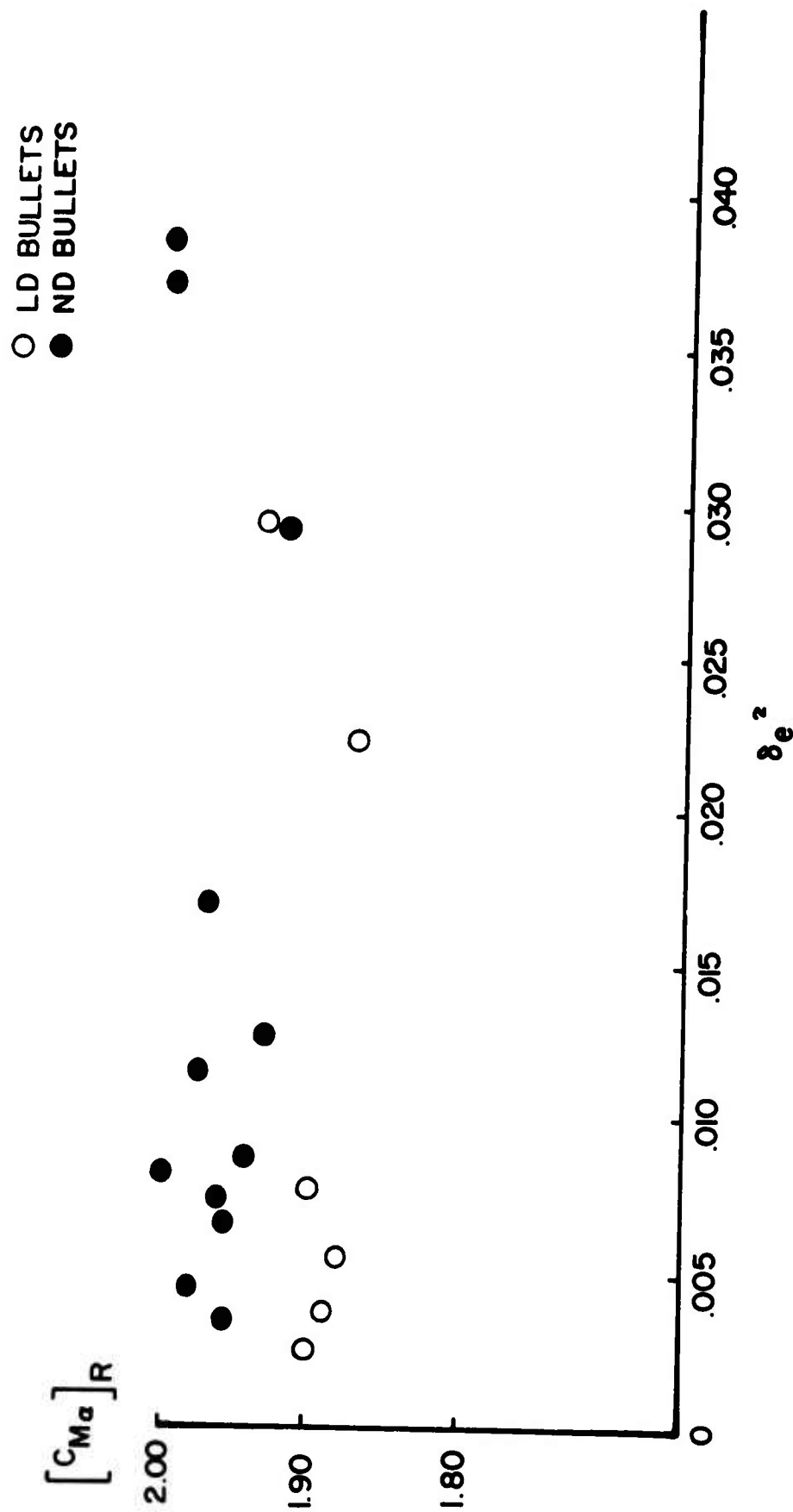
Figure 4. Overturning Moment Derivative Versus Effective Squared Yaw ($1 \cong 1.25$)
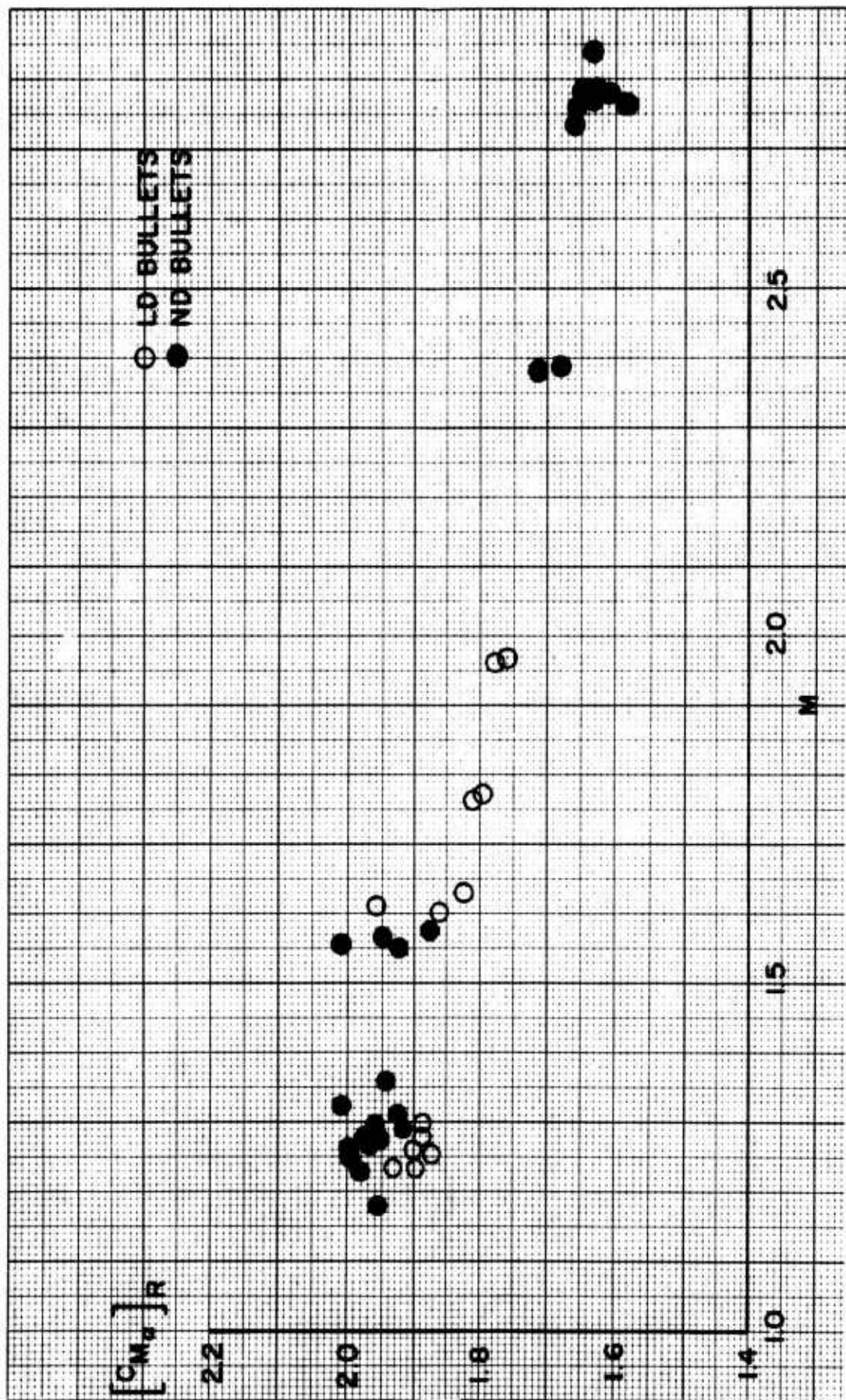
Figure 5. Overturning Moment Derivative Versus Mach Number

$$\left[C_{Mq} + C_{M\dot{\alpha}} \right]_R$$

○ LD BULLETS
● ND BULLETS

-6.0

-4.0

-2.0

0

0   .05   .10   .15   .20   .25   .30

δ_e^{*2}
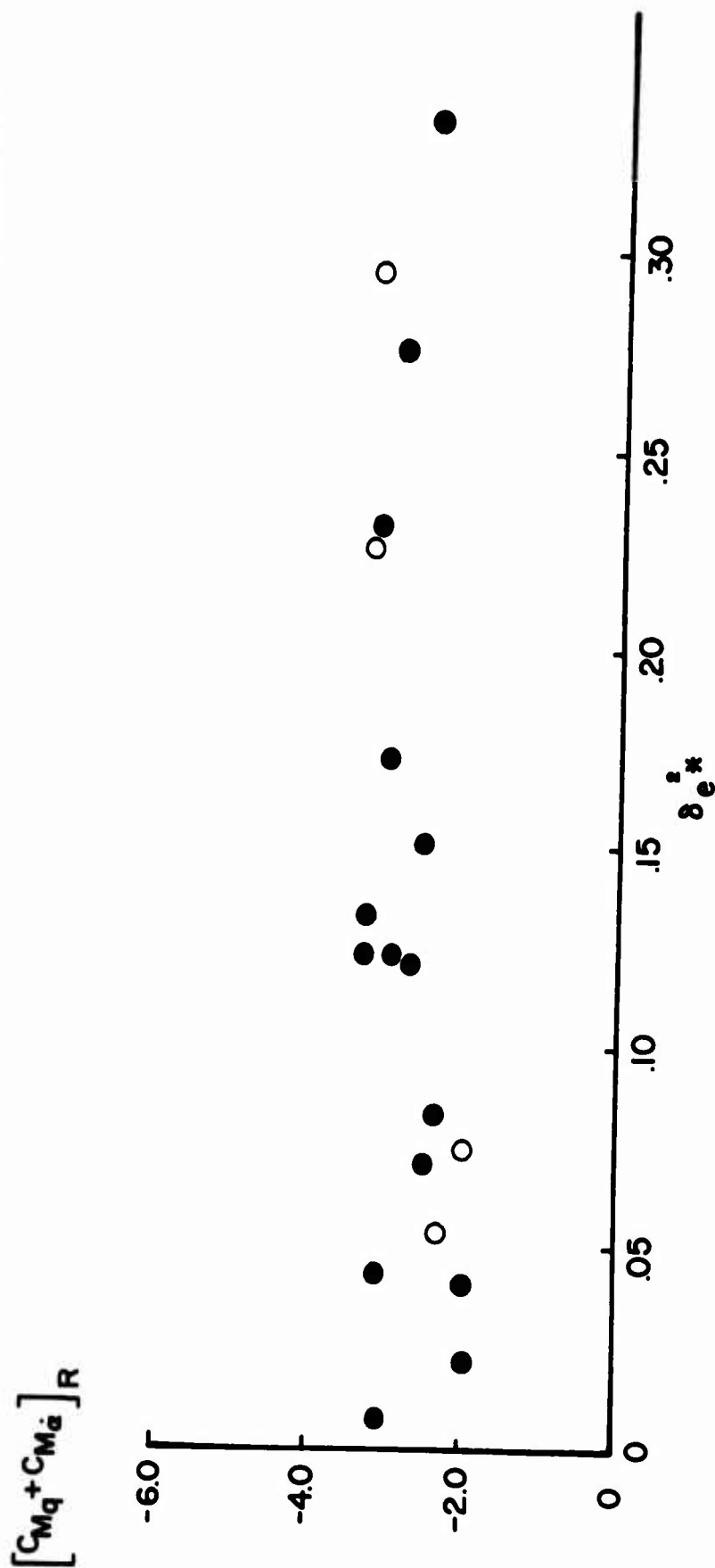
Figure 6. Damping Moment Derivatives Versus Effective Squared Yaw ($\tilde{I} \cong 1.25$)

31
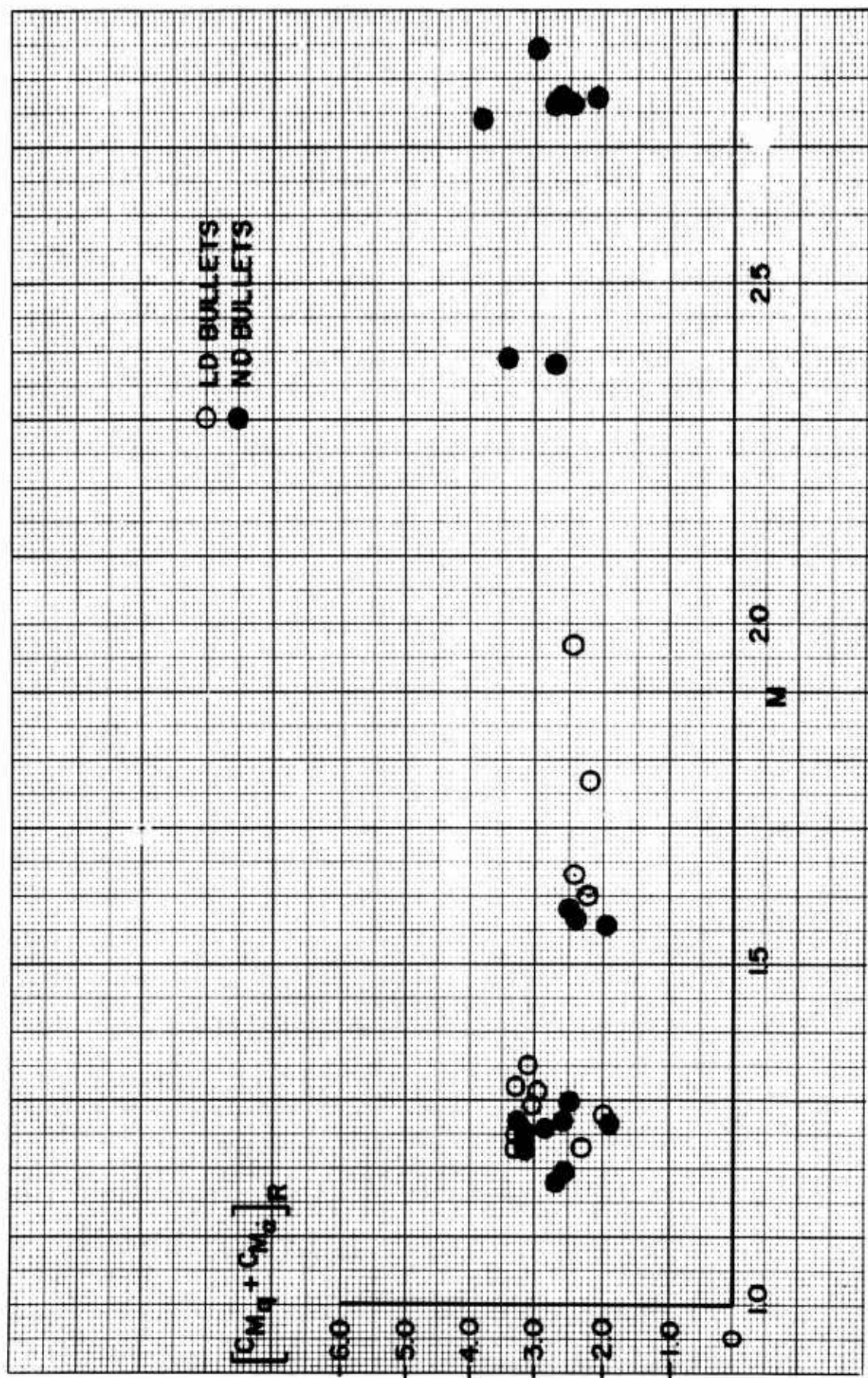
Figure 7. Damping Moment Derivatives Versus Mach Number
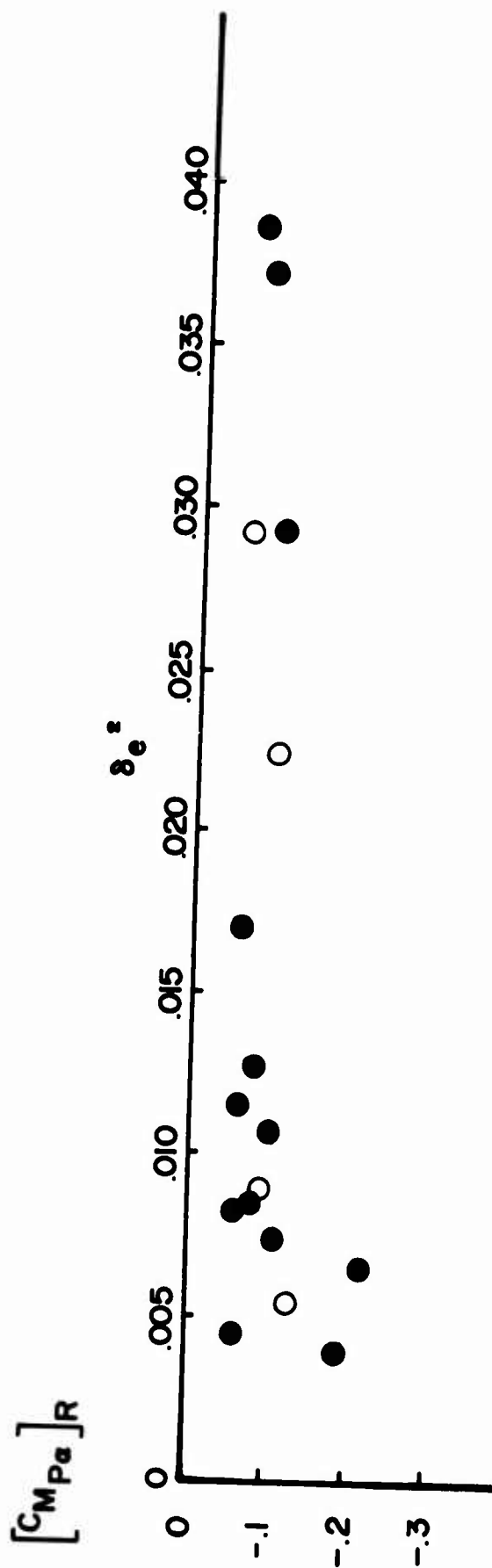
Figure 8. Magnus Moment Derivative Versus Effective Squared Yaw ($M \cong 1.25$)
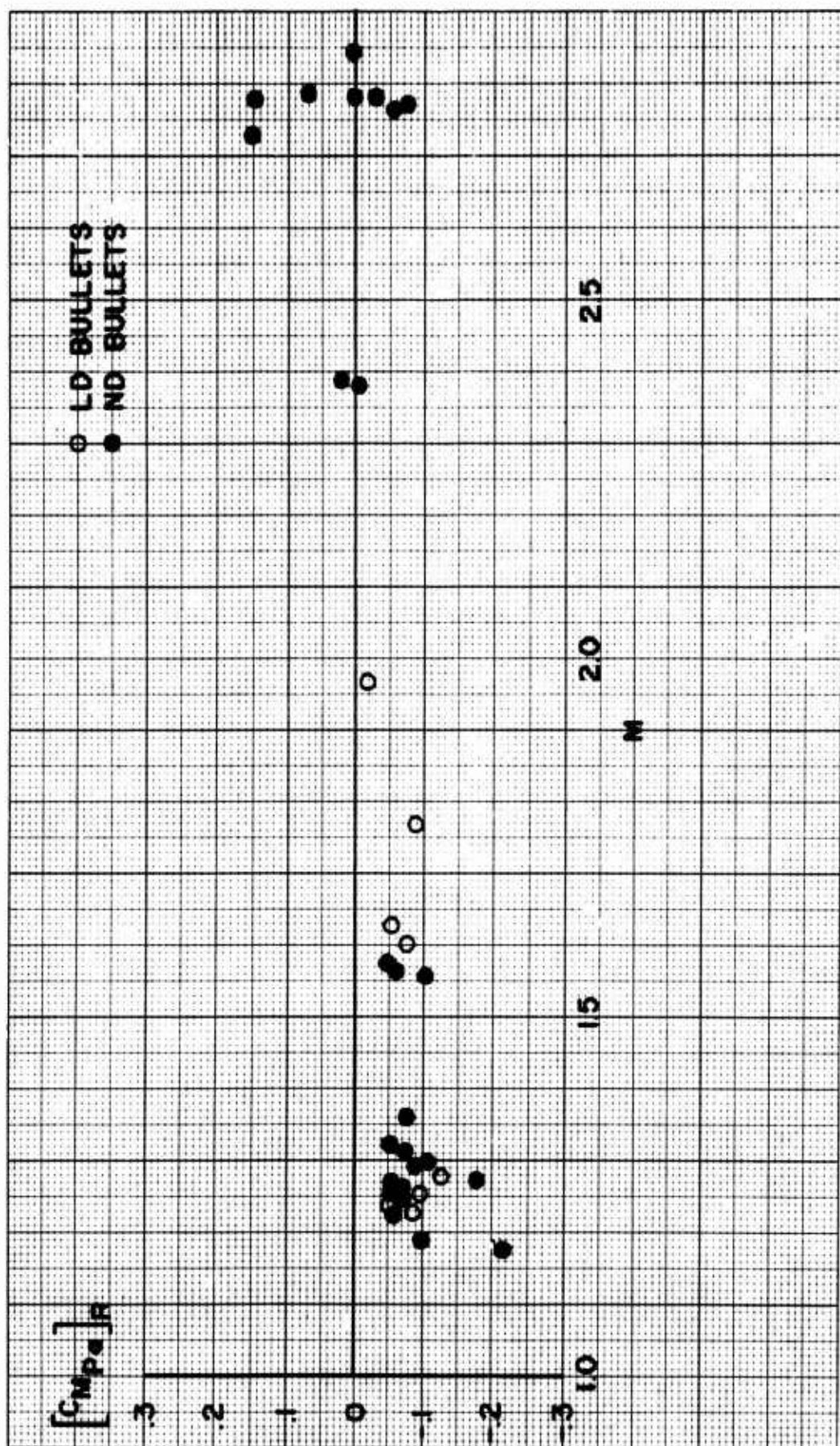
Figure 9. Magnus Moment Derivative Versus Mach Number

34
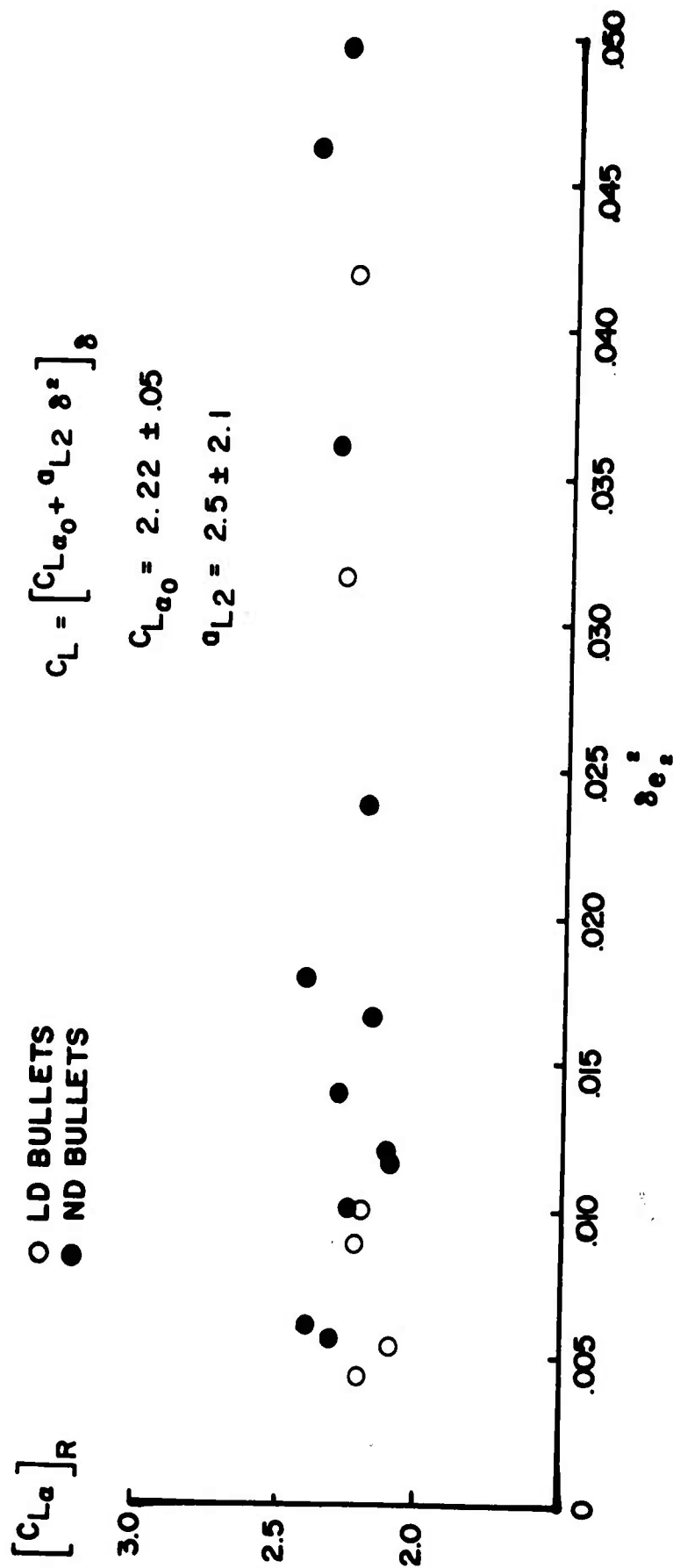
Figure 10. Lift Force Coefficient Versus Effective Squared Yaw ($1 \cong 1.25$)
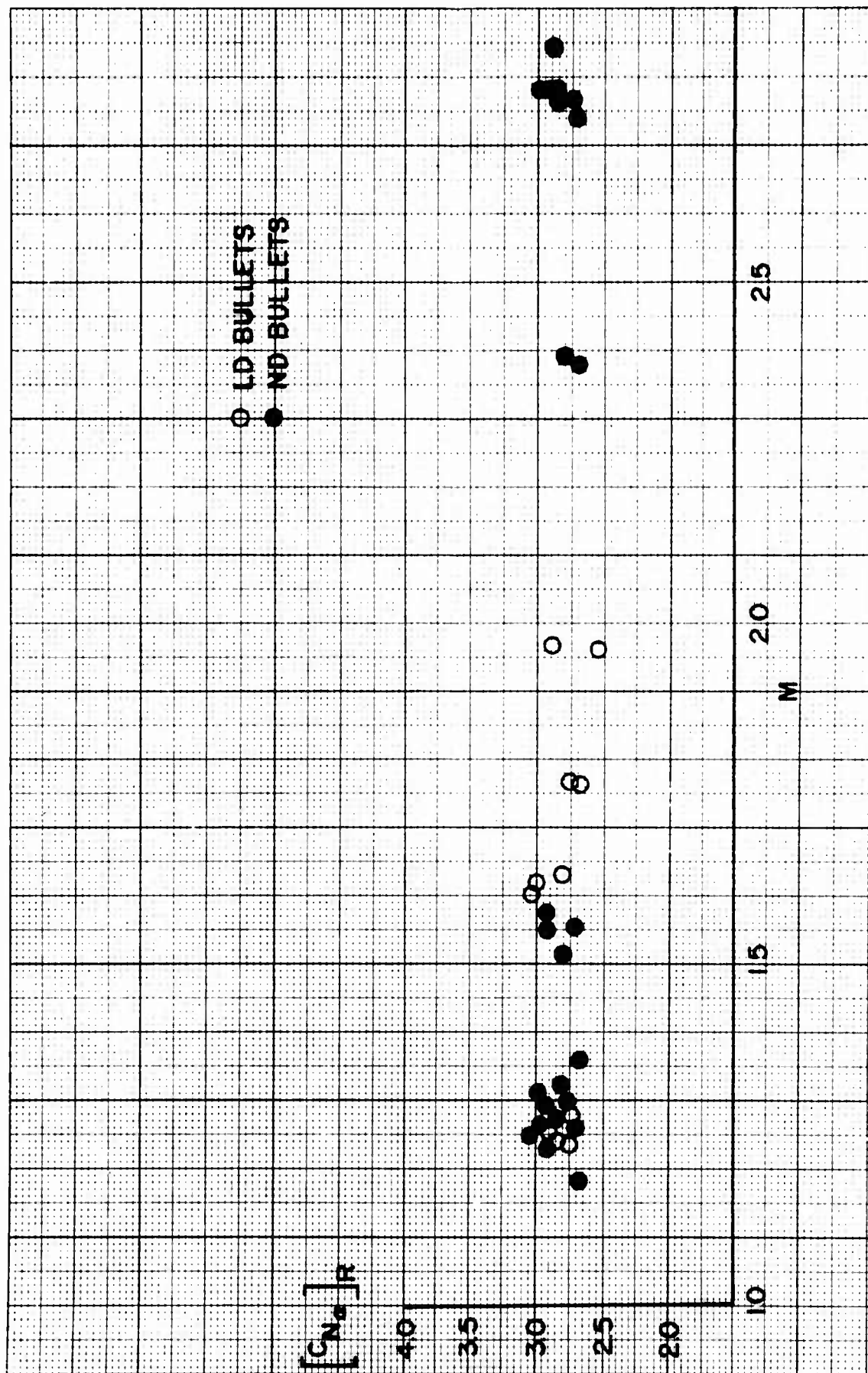
Figure 11. Normal Force Coefficient Versus Mach Number
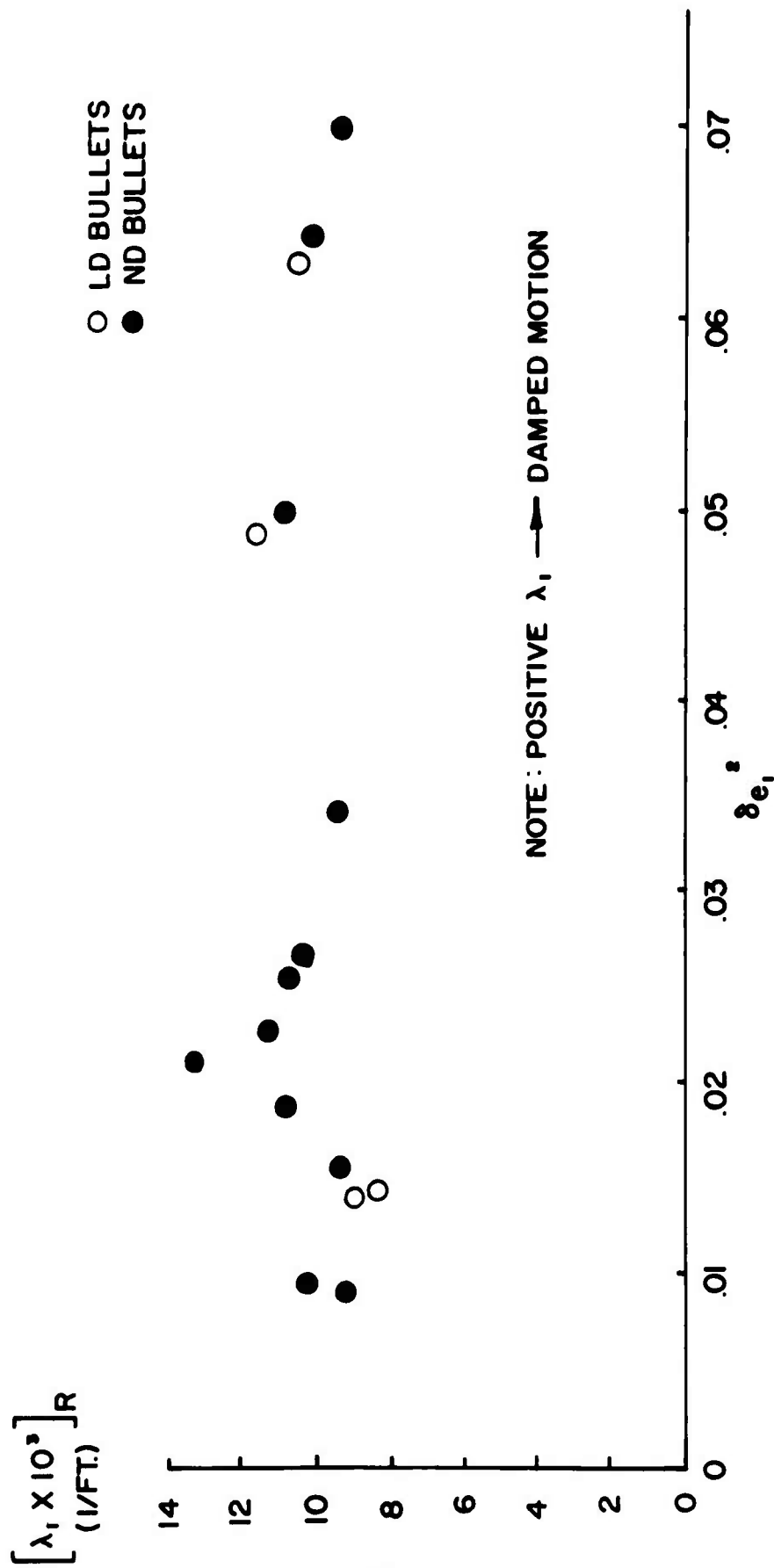
Figure 12. Nutational Damping Rate Versus Effective Squared Yaw ($M \cong 1.25$)
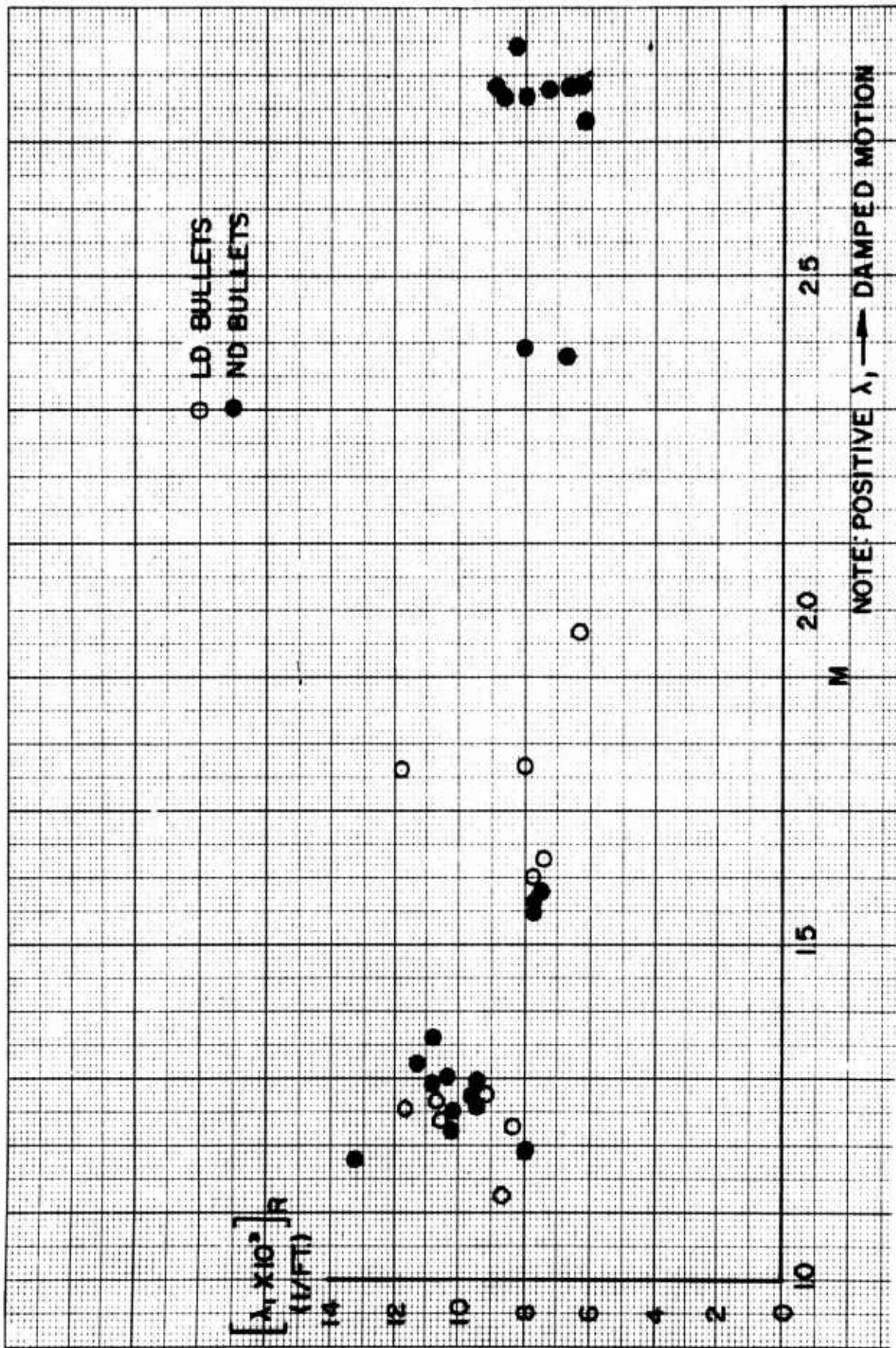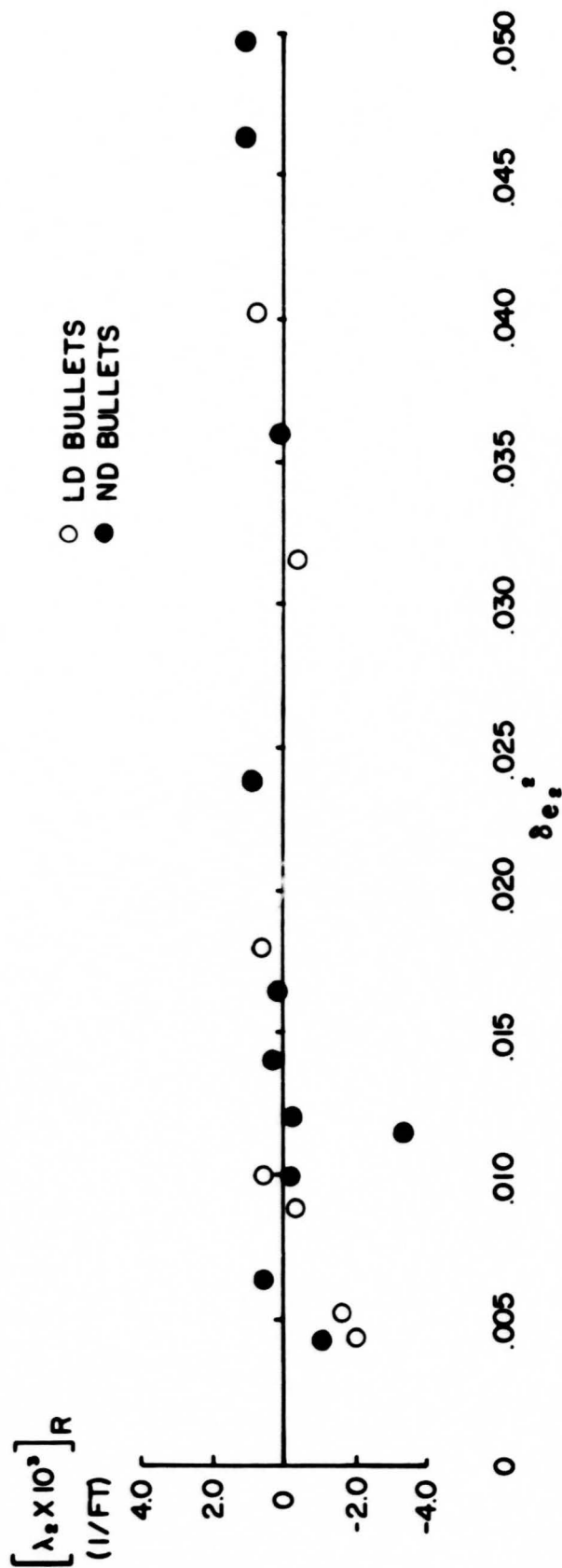
Figure 13. Nutational Damping Rate Versus Mach Number

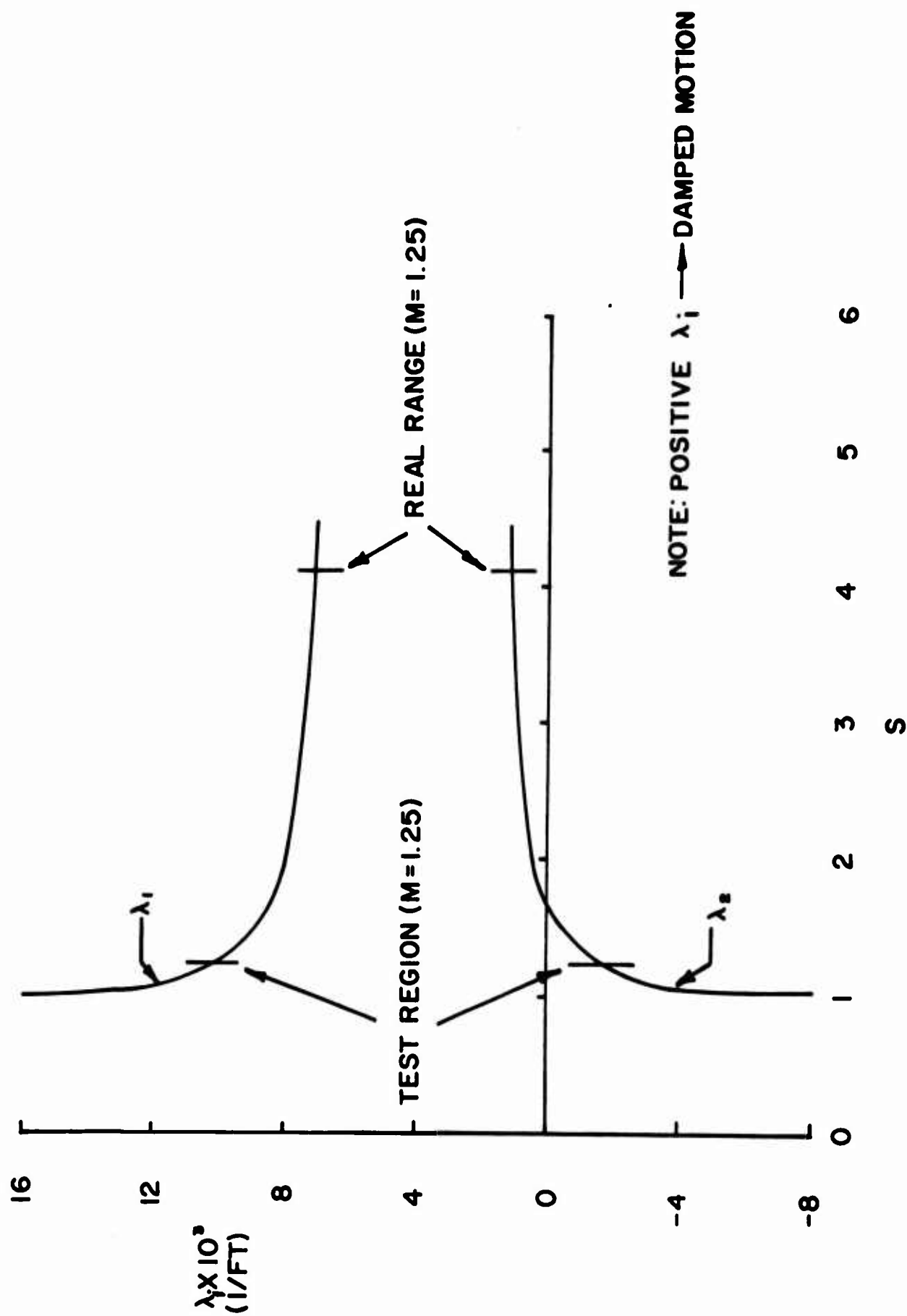Figure 14. Precessional Damping Rate Versus Effective Squared Yaw ($l \cong 1.28$)

Figure 15. Precessional Damping Rate Versus Mach Number

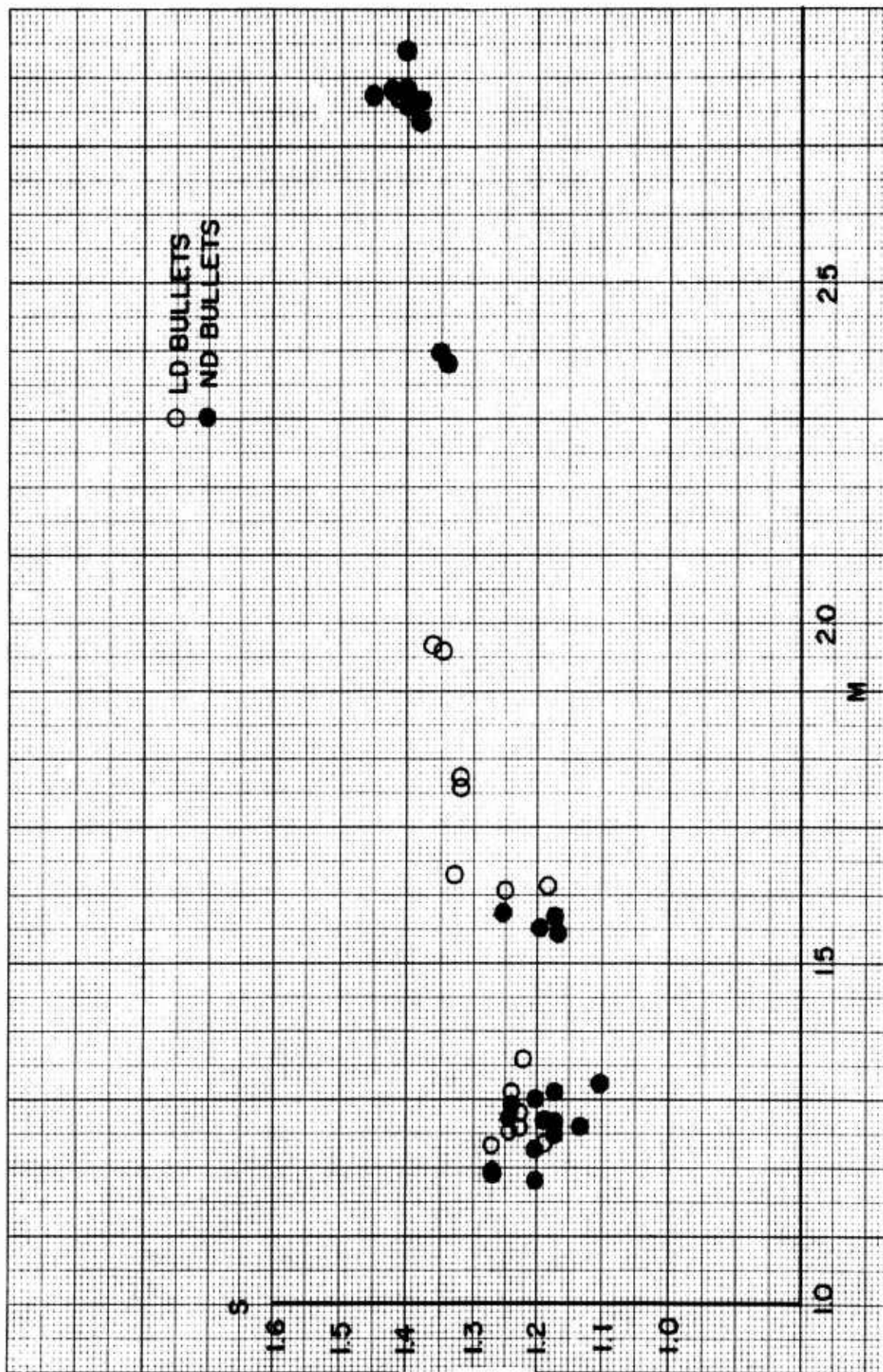Figure 16. Nutational and Precessional Damping Rates Versus Sigma

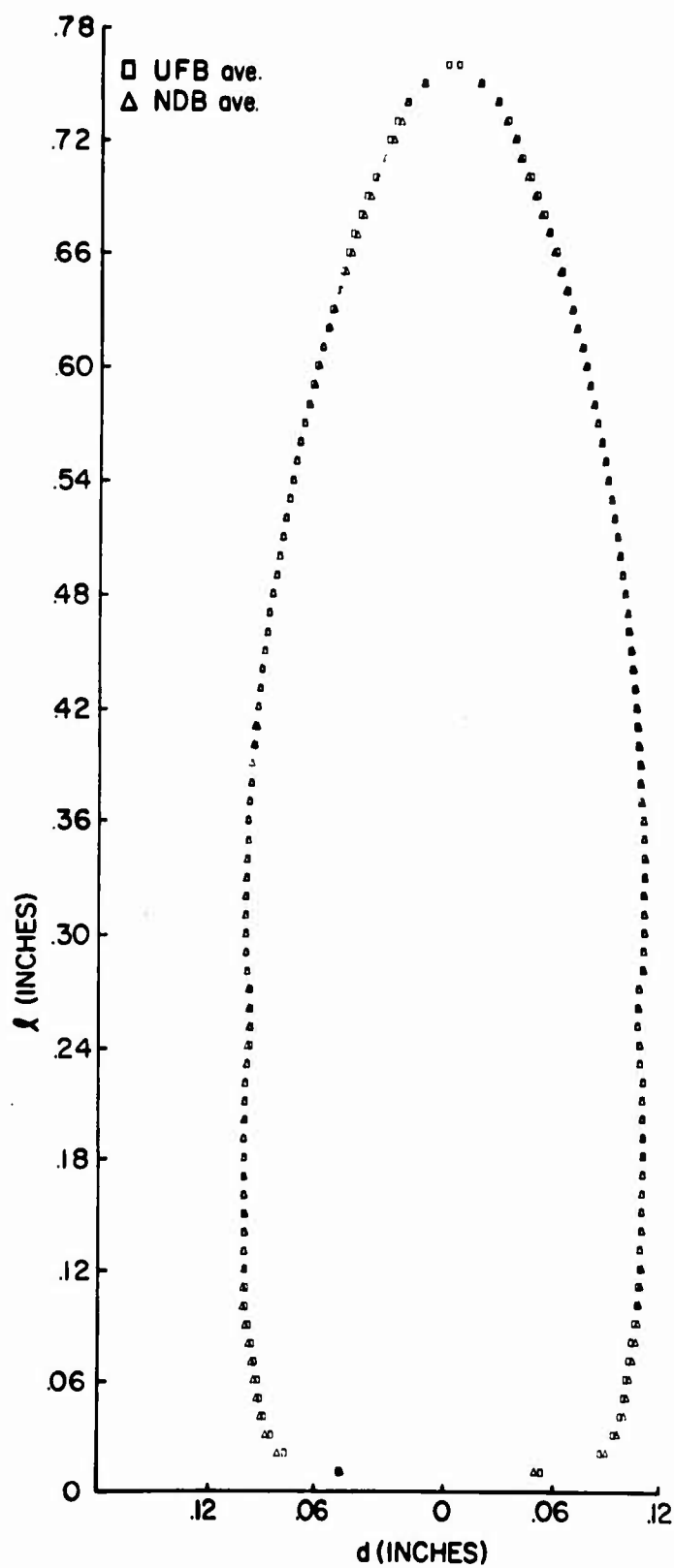Figure 17. Gyroscopic Stability Factor Versus Mach Number (s corrected to 1:12 in. twist)
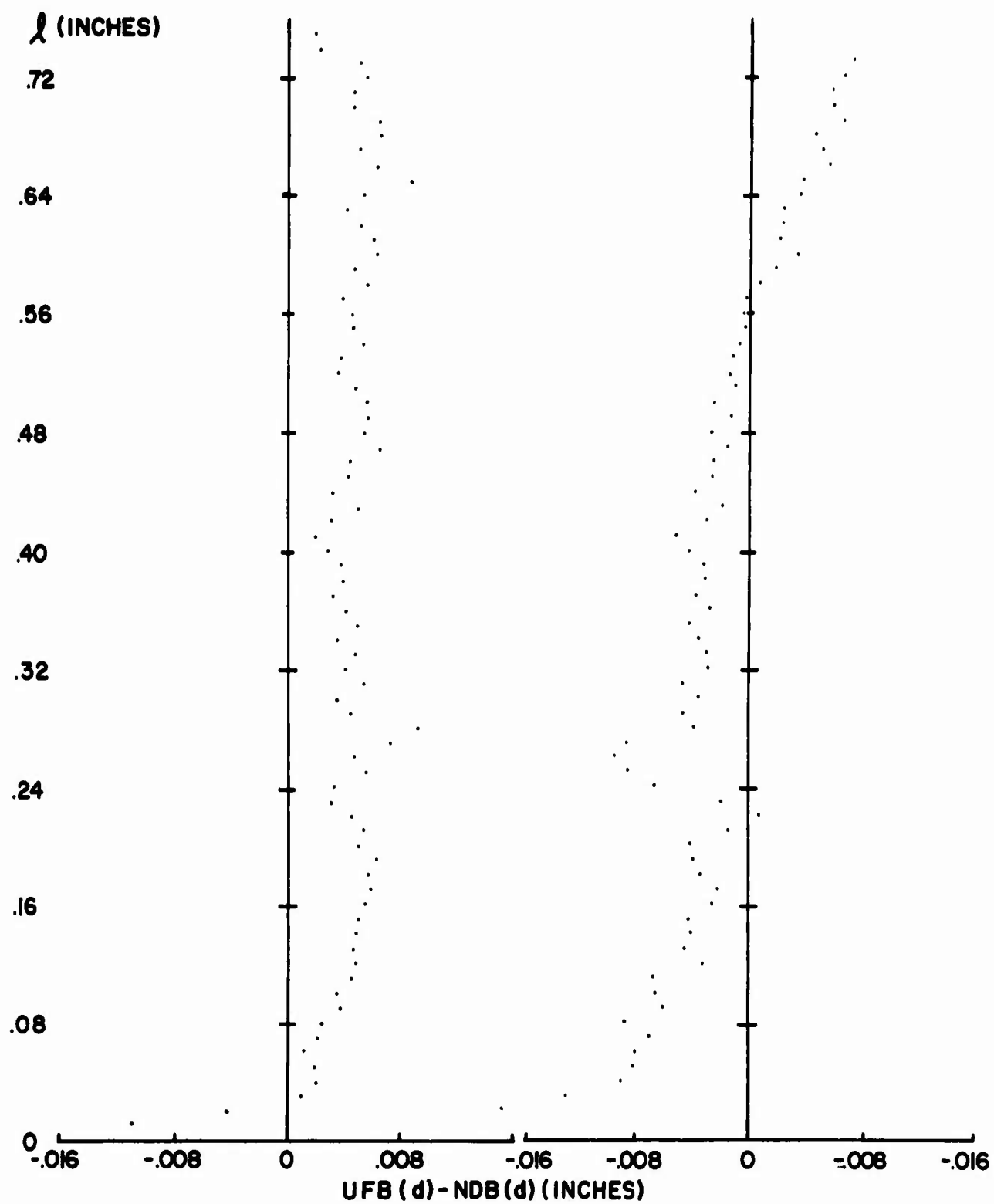
Figure 18. M-193 Contour (before and after launch)

43

Figure 19. Diametric Difference Versus Length
(average UFB-Individual NFB)

44

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) U.S. Army Aberdeen Research and Development Center Ballistic Research Laboratories Aberdeen Proving Ground, Maryland	2a. REPORT SECURITY CLASSIFICATION Unclassified	
	2b. GROUP	
3. REPORT TITLE DEFORMATION CHARACTERISTICS OF ONE LOT (LC SP412) OF 5.56mm M-193 AMMUNITION		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
5. AUTHOR(S) (First name, middle initial, last name) Maynard J. Piddington		
6. REPORT DATE October 1969	7a. TOTAL NO. OF PAGES 48	7b. NO. OF REFS 8
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO. RDT&E 1W562604A607	Memorandum Report 2016	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Commanding Officer, U.S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, Maryland.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Materiel Command Washington, D. C.	

13. ABSTRACT

The deformation characteristics of one lot of 5.56mm M-193 ammunition are presented and discussed. Physical measurements of the ammunition were taken before and after launch and the results compared on an individual basis. Rounds were launched at standard muzzle velocity, recovered and refired at a reduced velocity and compared with other rounds launched only at the same reduced velocity. Several before and after launch rounds were contour measured and comparisons were made on the shape of the projectile.

DD FORM 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
M-193 Aerodynamics						
Deformation						
Stability						
Physical Properties						
Contour Measurements						
Small Arms						